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Forest Succession in the Southern Limits of Early Wisconsin Glaciation As Indicated by a Pollen Spectrum from Bacon's Swamp, Marion County, Indiana

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A Fossil Pollen Study of Kokomo Bog, Howard County, Indiana

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A Pollen Profile of Otterbein Bog, Warren County, Indiana

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FOREST SUCCESSION OF THE SOUTHERN LIMITS OF EARLY WISCONSIN GLACIATION AS INDICATED BY A POLLEN SPECTRUM FROM BACON'S SWAMP, MARION COUNTY, INDIANA[1]

By JAMES H. OTTO

In the past few years, the Botany Department of Butler University has conducted an extensive study of Indiana peat bogs. Such a study will throw much light upon the history of Indiana vegetation. This paper is a portion of the greater survey and describes results from the southernmost bog studied.

The name "Bacon's Swamp" has its origin by common usage of natives of the region. The area is a typical glacial peat bog of the kettle hole type, and is in no sense a swamp. According to Potzger (15), "A swamp is a feature of the topography where the water table is above the surface and the soil is inorganic or of a humus nature." A bog, on the other hand, is "a feature of the topography where the water table is at or near the surface and the soil is of organic origin (peat) formed in situ." This location is, therefore, a true bog, but will be referred to in this paper as Bacon's Swamp.

Bacon's Swamp, located about the center of Marion county, Indiana, and nearly within the city limits of Indianapolis, presents a very interesting paleological problem due to its unique location. On the southern limits of the bog area of Indiana, it is a true Early Wisconsin peat bog, covering an area of approximately 30 acres and filled in with 32 feet of peat and marl. The Northern Moraine or Lake Region described by Malott (14) contains many bogs, but a bog in Marion county, approximately one hundred miles south, is indeed a rare occurrence. Therefore, the records from this bog are of special significance.

Cooper (6) describes the advance of the boreal forest "on the heels of the retreating glacier" on Muir Inlet, Glacial Bay, Alaska. His investigation shows the nature of succession at the present northern limits of the forest area. Bacon's Swamp, being near the southern glacial boundary of the Wisconsin ice sheet, is located uniquely to show succession when this great boreal forest had its northern limits in Indiana. The analysis of fossil pollen from Bacon's Swamp has also shown the invasion of the boreal forests by more southern species, which today in

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[1] This paper is a portion of a thesis in partial fulfillment of the requirements for the degree of Master of Arts in Butler University.

Indiana have reduced the older forests to boreal relicts such as those described by Friesner and Potzger (9) and (10).

GEOLOGY OF MARION COUNTY

Marion county, located near the center of the state of Indiana, lay in the path of several great continental glaciers of past ages. Little evidence of the earlier glaciers is left, due to the obliteration of the drift by the more recent Illinoian and Wisconsin ice sheets. This series of glaciers has greatly influenced the topography of the county. Malott (14) believes that the Illinoian ice sheet advanced through Marion county over a dissected area much like the driftless region of Central Southern Indiana, often referred to as the Knobs area. It covered the bed rock in Marion county with a drift in some places several hundred feet deep. The Illinoian glacial boundary is well defined in Indiana, showing a division of the sheet at the southern boundary of Johnson county. One arm continued southwest and one southeast, toward Cincinnati. Marion county, therefore, is located near the Illinoian glacial boundary.

A later glacier, the Early Wisconsin ice sheet, passed through Indiana and further altered the topography. It buried the Illinoian glacial formations with layers of drift as much as 50 feet deep in many places. Malott (14) shows the southern boundary of the Early Wisconsin glacier to be lobed in outline and running across Indiana in a general southeastern direction from Parke county. The southwest corner of Marion county is very near the boundary, as shown by several high moraines in the region of Glenns Valley and Mooresville, Indiana.

A second or Late Wisconsin ice sheet is believed to have passed over northern Indiana as far south as Logansport, in Cass county, approximately 60 miles north of Bacon's Swamp. Malott (14) refers to it as a Wisconsin substage. This would account for the abundance of lakes and bogs in that part of the state, commonly referred to as the Lakes Region. Such an explanation also dates the bogs south of the substage boundary as much older than the northern Indiana bogs. Bacon's Swamp is, therefore, of Early Wisconsin glacial origin.

BIOTIC INFLUENCES

Located in a large and rapidly expanding city, civilization has done much to alter Bacon's Swamp in recent years. The normal succession of vegetation in the bog has been hastened greatly by these biotic influences. It is interesting, however, that most of these changes have occurred recently. The author, having lived in the vicinity of the bog for the past 15 years, has observed many of these changes. Douglas (7), in 1905, described the area as a typical Sphagnum bog, bearing Sphagnum as richly as a Michigan or Wisconsin peat bog, or even better. Cain (4), in describing the vegetation of Bacon's Swamp, refers to small areas of living Sphagnum as late as 1927-1928. At the present, only very small traces of Sphagnum are left, and the bog has advanced to the Calamagrostis-meadow stage. The disappearance of Sphagnum is due to the annual fires which sweep the sedge-meadow.

Ten years ago, Bacon's Swamp was widely known as an excellent area for study of aquatic flora and fauna. The basin contained water throughout the year and flooded to a shallow lake stage in the spring and fall. Many species of water birds stopped at the lake during the spring migratory season, and some remained throughout the summer. The author recalls seeing broods of ducklings and the young of herons, bitterns, and other waterfowl. The bog also provided suitable habitat for many species of reptiles and amphibians, as well as aquatic mammals such as muskrats.

Comparing the conditions in the bog today with those of such a short time ago, it seems unbelievable that so many changes could have occurred. One of the early biotic influences was the attempt in 1914 to extend a street through the middle of the bog. A roadbed of gravel and dirt was laid above the peat mat, and the road was completed. However, the following year, the weight of the roadbed compressed the peat and the road disappeared. This produced an interesting rectangular pond in the center of the swamp. Cain (4) states that this pond would appear quite strange to one who did not know its origin. The road was abandoned from 1915 until about two years ago when the project was renewed. Several times in the past two years the road has been completed and would support the weight of trucks, only to sink again below the surface following further compression of the peat. The weight of the fill has forced the peat out on both sides of the road in large mounds several feet high. Another more successful attempt to construct a road has been made several hundred feet to the north across the north arm of the swamp.

Perhaps the greatest changes in the topographical and vegetational features of the swamp are the result of a lowering of the water table in the past 10-15 years. The exact reason for this drying out is somewhat questionable. In its present condition, the swamp dries out each summer with the exception of the pond formed by the sunken street and a small water hole in the southwest end. The water table, during that season, is one to two feet below the surface of the mat. Cain (4) suggests that the lowering of the water table is due to tilling of the surrounding land. A drain in the north end of the bog has also helped to lower the water table.

Still another factor influencing the present vegetation in the bog is the periodic autumn burning of the dried grasses and sedges. The author has observed annual fires occurring about the month of August for the past eight to ten years. Most of these blazes are probably of incendiary origin. The desiccated plants in the meadow at that season produce a roaring fire which destroys all vegetation in its path, and even burns several inches into the peat. Holes of such origin may be found in many places, particularly in the southwest corner where the Calamagrostis-meadow is best developed.

The swamp forest has been partially destroyed quite recently as a result of cutting and clearing. The trees were too small to be of commercial value, but were removed as a part of a project to reclaim the land. The forest in the north end especially has been damaged in this manner.

PRESENT VEGETATION

The influence of civilization which has so greatly altered conditions of the bog in recent years, has also produced some interesting features in the vegetation. The lowering of the water table occurred over such a relatively short period that several stages in the succession of the hydrosere exist in the swamp at the present time. Mingled with the plants now controlling, are species of a more hydrophytic nature which flourished a short time ago.

As in many other peat bogs, the vegetation of Bacon's Swamp occupies rather definite zones. The central area is now controlled by *Calamagrostis canadensis.* Mingled with the grasses in the wet meadow are *Dryopteris thelypteris pubescens, Juncus canadensis,* and *Hypericum virginicum.* In the southwest end, scattered islands of *Decodon verticillatus* remain from a time of more hydrophytic conditions. Cain (4) refers to these islands and accounts for their existence by the presence of somewhat deeper water in that end of the swamp. In 1927 the Decodon islands were quite prominent, but since that time have been invaded by the wet meadow. Other relics of more hydrophytic conditions are scattered clumps of yellow pond lilies (Nymphæa) growing in low places in the meadow. Typha is restricted somewhat to areas near the deepest part of the bog, where some water remains throughout the year except during very dry seasons.

Like many other Sphagnum bogs, Bacon's is surrounded by a moat. This area of open water is, in most places, 15 to 20 feet wide, and extends from the margin to a zone of Cephalanthus which borders on the Calamagrostis-meadow. At present, much of the Cephalanthus is dead, but the width of the zone indicates more favorable conditions a short time ago. Cain (4) found much of the Cephalanthus to be dying out in 1927, and remarked about the large amount of dead wood and the extensive root systems to support very few living branches.

Another interesting zone of vegetation is occupied by *Salix nigra*. Perhaps this area should be included in the swamp forest, but is restricted to the moat and to a few low places in the southwest portion of the wet meadow. The willow occupies a zone outside of Cephalanthus for the most part, but in some places mingles with it.

The swamp forest proper surrounds the bog. One of the most prominent species of this area is *Fraxinus profunda,* which in several places exists in nearly pure stands. One of these stands is located along the west shore of the north end of the bog. Other constituents of the swamp forest include *Acer rubrum, Ulmus fulva, Nyssa sylvatica, Quercus bicolor*, and *Quercus palustris.*

The upland forest around the bog is typical for central Indiana, composed of *Fagus grandifolia, Acer saccharum, Acer saccharinum, Quercus alba,* and *Quercus borealis maxima.* Associated with these in lower frequency classes are Fraxinus sp., Carya sp., *Liriodendron tulipifera, Prunus serotina,* and *Gleditsia triacanthos.* Cultural influences have almost entirely eliminated this climax forest.

METHODS

Four sets of peat samples were obtained over a period of several years. Under the direction of Dr. J. E. Potzger, classes in ecology made three borings; the fourth set was obtained during the winter of 1936. All of the borings were made in an approximately straight line across the southwest portion of the bog. Boring IV was made at a point about 250 feet from the east shore and about 100 feet south of the pond formed by the sinking of the roadbed of Fifty-sixth street into the bog. This was the deepest of the four borings. Boring I was made about 150 feet southwest of IV. The other two borings were made in a straight line with I and IV. Boring III was taken about 300 feet southwest of I and II, 150 feet from III. Boring II was made within 150 feet of the west edge of the bog.

The samples were taken with a special peat borer, consisting of a hollow chamber with a movable sleeve, permitting the cylinder to be opened and closer below the surface by turning the handle. Material was collected at each foot level, beginning with one foot below the surface, and the portion to be used for examination was taken from the center of the core, thus reducing the possibilities of contamination. As an added precaution against contamination, the chamber was thoroughly washed between collection of samples. Each sample was placed into a small bottle and labeled. Upon returning to the laboratory, the bottles were sealed with paraffin to prevent drying out.

Separation of the peat and slide preparation followed, with a few modifications, the method suggested by Geisler (11). It was found that the preparation of slightly more peat than the amount suggested by Geisler increased the pollen content of the slides. Into a small beaker (25 cc) was placed a heaping scalpelful of peat. To this sample was added about 15 cc of 95 percent alcohol. The peat was then stirred gently with a camel's-hair brush until the floccules had mixed thoroughly with the alcohol. Four drops of 1 percent aqueous gentian violet stain were then added and the material stirred thoroughly for several minutes. The suspended peat was allowed to settle out after stirring. By means of a pipette, the upper surface of the precipitate was skimmed. Several drops of material were placed on a glass slide until the alcohol had nearly evaporated. While the peat was slightly moist, a drop of glycerin jelly was added and the material mixed thoroughly with the jelly by means of a clean camel's-hair brush. A cover slip was then added to the slide. It was found that the pollen grains darkened for several days after mounting, so all slides were allowed to stand for at least two days before examination. Few grains were broken, and the pollen was well separated from the peat.

Pollen determination was accomplished by comparison with modern pollen and the descriptions and illustrations of Wodehouse (23) and Sears (18). The pollen frequency was based on a count of 200 grains, except in the lower levels where few species were represented, and in some of the upper levels where pollen grains were scarce, in which cases, 100 grains were counted.

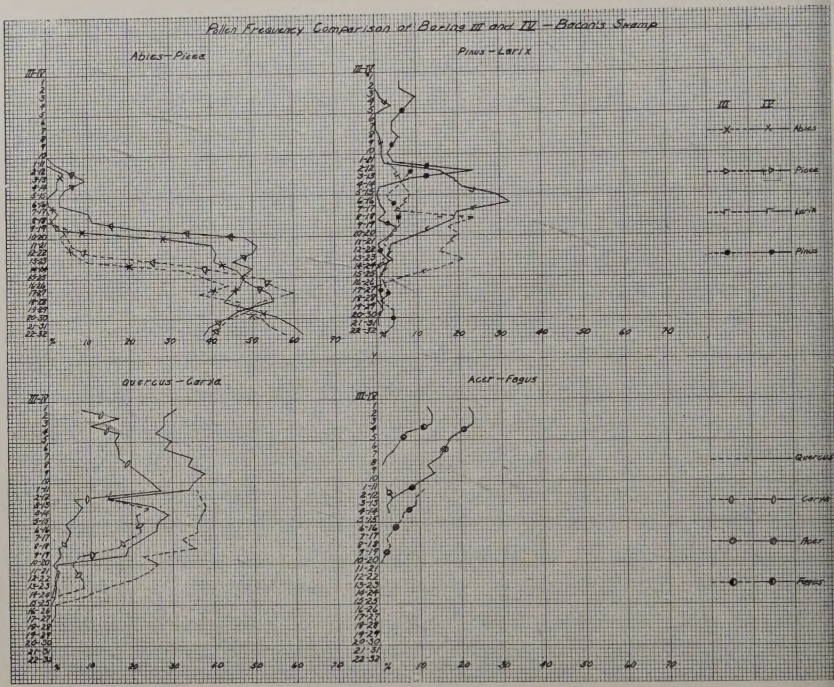
OBSERVATIONS

In all, four borings were made, but only two were selected for pollen analysis. Boring IV was chosen because of its depth, 32 samples having been obtained. Boring III, 22 feet deep, was used because of its greater distance from boring IV. The results of the pollen analysis of boring IV are presented in graph form in figure 1. The results from the two borings were very similar, both in the nature of the peat obtained and in pollen content, even though the two sets of samples were obtained in opposite ends of the southwest region of the bog. The upper seven levels in boring IV were composed of raw Sphagnum peat. Levels 8 through 15 were of a very coarse Carex peat. These samples were composed largely of the sedge remains through which were scattered bits of decayed Sphagnum. Below the Carex deposit, levels 16 through 23 were filled in with decayed Sphagnum peat. The bottom of this layer was so decomposed as to form a black jelly-like ooze. The lower nine levels, from 24 through 32, were marl. In the 32-foot level, the marl was mixed with coarse sand crystals, which would indicate the old lake bottom.

The pollen spectrum of boring IV reveals many changes in the forest cover of the Bacon's Swamp region since formation of the bog. Indicated in the spectrum is a forest succession from a boreal coniferous type to the broad-leaved mesophytic climax forest of today. Abies and Picea controlled during deposition of the lower levels. At the 32-foot level, 62 percent of the pollen represented was Abies. From this point, however, Abies declined and Picea pollen increased to higher frequencies to assume dominance over Abies. Control of the forest by these conifers continued until the 21-foot level. Here, Abies declined rapidly from 40 percent in the 21-foot level, to 2.5 percent in the 19-foot level, never showed dominance after this, and disappeared at the 11-foot level. Picea soon followed Abies, dropping from 48 percent in the 20-foot level, to 3 percent in the 16-foot level, and disappeared from the spectrum at the 10-foot level. Among the low frequency representatives of the lower 20 levels in the bog were Larix, Pinus, and the Salix-Populus group.

Interesting forest changes occurred while the levels 20 to 10 were deposited. With the rapid decline of Abies and Picea, other genera showed a marked increase. Larix, which had been represented in low frequency from the 31-foot level, increased rapidly at the 21-foot level. This increase continued to a peak of 32.5 percent in the 16-foot level. At that point, the percentages dropped steadily to 2 percent in the

FIGURE 2



11-foot level. Larix continued to the 2-foot level, but was represented only by low pollen frequency. The 20-foot level also marked the rapid increase of Quercus, Salix-Populus, and the Betula-Alnus-Corylus group. Quercus increased to 29 percent in the 14-foot level, and, after a slight drop in the 12-foot level, reached 35.5 percent in the 10-foot level. Salix-Populus remained about 15 percent to the 16-foot level, and then decreased. Betula-Alnus-Corylus also occupied a secondary position in the spectrum through the middle ten levels. Pinus, appearing first in the 28-foot level, continued in the lower frequencies to the 14-foot level, where a rapid increase was observed. The peak for Pinus, 23.5 percent, occurred in the 12-foot level. It declined to 10 percent above that point but persisted to the surface. Another broad-leaved invader of the coniferous forest was Carya. It appeared in the 23-foot level and evidenced little competition until the 12-foot level, where it suddenly increased from 6 percent to 27.5 percent.

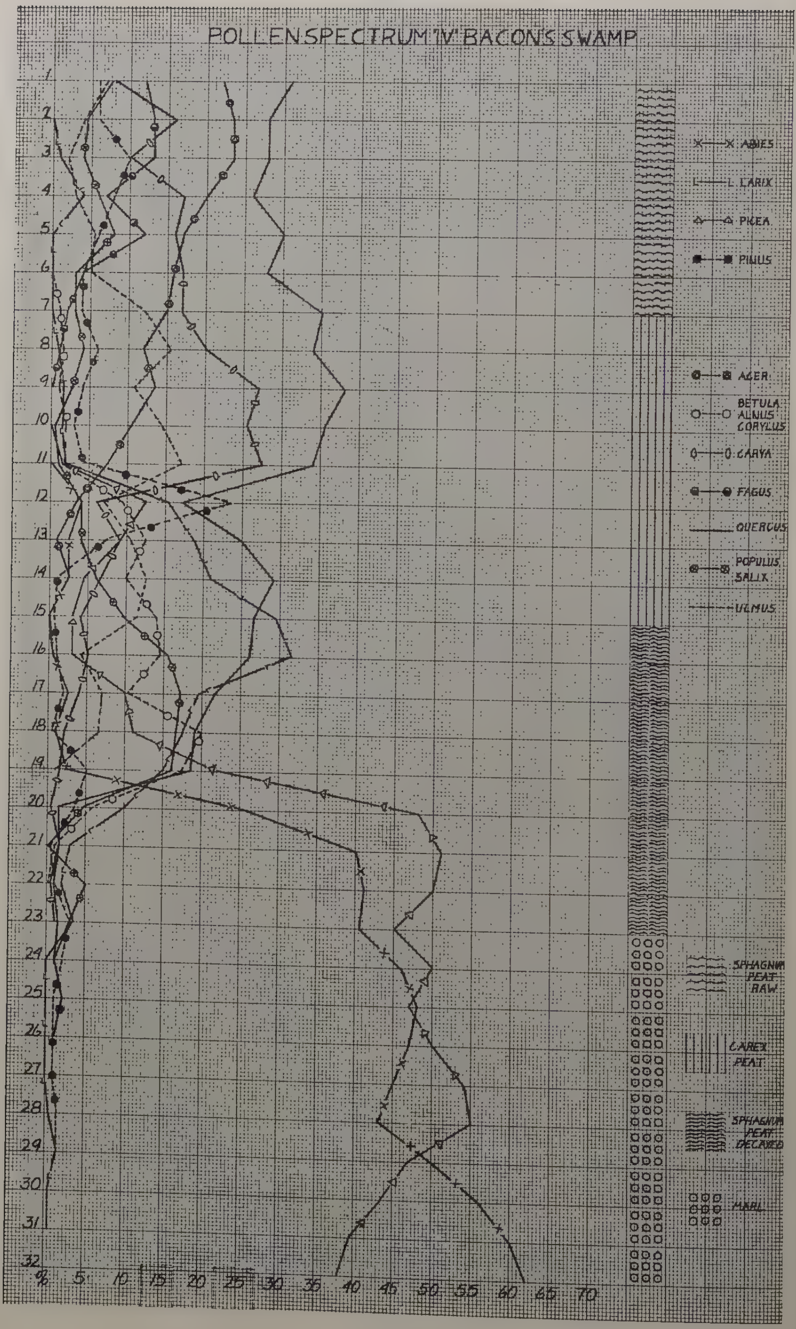
A third period of the forest succession, shown in the upper ten levels of boring IV, indicates a further advance toward a broad-leaved mesophytic climax forest, and a compensating reduction of genera prominent in the middle ten levels to secondary importance. Quercus shows no increase, but continues to be a dominant genus. Carya was also present in all of these levels but declined gradually from the 9-foot level to a frequency of 8 percent at the 1-foot level. Acer made its appearance at the 14-foot level and increased steadily to a 22 percent peak at the 1-foot level. This percentage is more significant if we consider that Acer produces but a small amount of pollen as compared with Carya and Quercus. Fagus came in at the 9-foot level and increased to 12 percent at the 1-foot level. The upper levels of the bog show Quercus, Acer, and Fagus as the dominant genera, while Carya, Salix-Populus, Ulmus, and Pinus decreased in frequency to secondary importance. As stated previously, Larix remained to the 2-foot level.

Juglans, Tilia, Fraxinus, and Thuja were represented in boring IV, but only as genera of secondary importance. These genera were omitted from the spectrum diagram, in figure 1, to simplify it. Tilia appeared in several levels above 20 feet, but showed no consistent increase or decrease. Juglans remained in the low frequency classes below the 10-foot level, and gradually increased to 10 percent in the 6-foot level, after which it decreased to about 5 percent and was thus represented to the surface. Fraxinus and Thuja were represented by only a few pollen grains in the upper levels.

In general, the pollen spectrum of boring IV may be divided into three periods. The lower 12 levels, from 32 to 20 feet, were controlled by Abies and Picea, with Pinus, Larix, and the Salix-Populus group present in the low-frequency classes. Levels 20 through 10 showed a rapid decrease of Abies and Picea and an increase in Quercus, Larix, Salix-Populus and the Betula group. In the 12-foot level, Pinus increased rapidly to a peak of 23.5 percent, but declined rapidly from that point. The spectrum again changed in the upper ten levels. Quercus maintained a high frequency to the surface, Carya decreased gradually, and Acer and Fagus increased to a position of codominance with Quercus.

Figure 2 shows a special comparative study of results obtained in boring II and boring IV. Four graphs were used to compare the genera which were most prominent in the pollen spectra of the two borings. In plotting the graphs, an attempt was made to arrange the 22 levels of boring III in time sequence with the 32 samples from boring IV. Assuming the bottom levels to be comparable, level 22 of boring III was

FIGURE 1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PICEA
PINUS
ACER
BETULA ALNUS CORYLUS
CARYA
FAGUS
QUERCUS
POPULUS SALIX
ULMUS
SPHAGNUM PEAT RAW
CAREX PEAT
SPHAGNUM PEAT DECAYED
MARL

made to correspond with level 32 of boring IV. The graphs shown in figure 2 reveal a striking similarity in the spectrum curves of the two borings.

This similarity between borings is well illustrated in the Abies-Picea graph. These conifers are shown to have dominated the spectrum during the same period in both borings. Both curves show an early dominance of the two conifers for about the same length of time, followed by a rapid decline in frequency. Similarity is shown, also, in the rapid disappearance of Abies and Picea from the spectrum of each boring. Another striking feature of the graph is the fact that while the same relationship exists between Abies and Picea in the borings, the curves seem to indicate a time error in the arrangement of foot-levels on the graph. An interval of about four feet separates the lines of the two spectra. If the frequency curves of boring III were plotted four foot-levels higher, the two borings would show a very close Abies-Picea correlation.

The other graphs also show a close relationship between the results of boring III and boring IV. The frequencies of Quercus and Carya show the same trends, although the lines of boring III again seem to be placed too low on the graph. The decrease of Carya is much more complete in the upper levels of boring IV than in III, suggesting that the 1-foot level of the latter is considerably older than the 1-foot level of boring IV. The rapid increase of Quercus beginning in the 20-foot level of boring IV is shown in the 15-foot level of III. Pinus was present through both spectra, but in the lower frequency classes. Larix showed the same rapid increase in the mid-sections of the borings, followed by sudden decrease, but again, about four or five foot-levels separate the curves representing the Larix frequency in the two borings.

Further evidence to indicate the absence in boring III of the pollens found in the upper levels of boring IV, is shown in the Acer-Fagus curves. Acer shows a frequency of 24 percent in the 1-foot level of boring IV and only 11 percent in the 1-foot level of III. Fagus, represented in eight levels in the deep boring and reaching 12 percent in the 1-foot level, was found in only two levels and in the low frequency classes in the 22-foot boring. As in the other three graphs in figure 2, raising the curves of boring III about four or five levels would result in a close correlation of the Acer-Fagus lines.

ACIDITY OF BORING IV

A study was made of the pH values of every level of boring IV. Readings were made with the Youden hydrogen-ion apparatus. Three readings were made for each of the 32 levels of the boring and their active acidities were averaged for an average pH value for each level. The results indicate a gradual decrease in acidity from upper levels of peat to the marl in the bottom of the basin. The peat at all levels was acid to slightly acid, while the marl was alkaline. It is interesting to note, however, that none of the peat showed a strong acidity. The 1-foot level, with a pH of 5.9, was the most acid in the bog. The other raw Sphagnum layers were decreasingly acid to the 8-foot level with a pH of 6.82. Carex and decayed Sphagnum peat, occupying the next layers from 8 to 23 feet, were found to be slightly acid, with an increase in acidity in levels 22 and 23. At the 24-foot level marl made its appearance and the acidity dropped to nearly neutral (6.9). Alkalinity increased to the bottom of the marl deposit. The highest alkalinity, pH 7.3, was found at the 30-foot level.

Acidity in the upper levels of the bog may be accounted for by the activity of Sphagnum and other mosses. The more rapid decay of the plant remains in the upper levels would also increase acidity. The most acid peat was at the 1-foot and surface levels, where the Sphagnum mosses have been active most recently. The acidity of these layers decreased to the Carex peat below. Newly formed peat which is near living Sphagnum is acid, but, as the mat becomes deeper, these levels become less acid. This decrease in acidity is evidently due to the entrance of water from the surrounding area, for the glacial till contains considerable limestone and shell debris from which the calcium carbonate may go into solution. The bog basin receives much water in wet seasons, thus permitting the limy material to seep down into the lower levels of the bog. Another cause for the decrease in acidity is the effect of fires which burn over the surface of the bog periodically. The alkaline ashes are washed into the peat and gradually seep into the lower layers, thus decreasing the acidity of the deposits.

The results of the pH study in Bacon's Swamp agree with those of other Indiana bogs as found by Potzger (16) in 11 Indiana bogs, including Bacon's. He found all of the bogs to be acid near the top, only slightly acid about the middle, and alkaline in the lower levels.

DISCUSSION

Discussion of such phases of the investigation as the validity of fossil pollen analysis as an indication of forest succession has been omitted because of adequate treatment of the subject by other investigators. G. Erdtman (8), Barkley (1), and others, have shown that reliable data may be obtained by the determination of the pollen content of peat. Correlation of results obtained from pollen analyses of numerous bogs in the Central States and Canada further testify to the validity of this branch of ecological research. Likewise, a discussion of various methods for separation of pollen from peat has been omitted. The method devised by Geisler (11) and used by Barnett (2), Prettyman (17), and Smith (21), yielded satisfactory results in the present study. The pollen spectrum obtained from borings in Bacon's Swamp agrees with the results obtained by Barnett (2) in Emporia bog, Madison county, and Prettyman (17) in Fox Prairie bog, Hamilton county, Indiana. The correlation found between these bogs is of special interest because of similarity in geological history. The three bogs are located below the southern boundary of the Late Wisconsin glacial substage and are therefore older than the bogs of northern Indiana. Any extensive migration of the forests recorded by the presence of preserved pollen grains in the peat, should be evidenced in the pollen spectra of all three bogs. A close correlation of results between the bogs further proves the validity of pollen analysis as an indication of forest succession.

The pollen in the lower eight levels of the three bogs revealed high Abies and Picea frequencies. A very rapid decline of the conifers followed by an increase in frequency of broad-leaved pollen marked another similarity. Salix, Ulmus, Quercus, Carya, Juglans, and the Betulaceæ appeared, in all cases, in the middle peat levels, although the frequencies varied, due probably to the local environment of the bogs. Quercus showed a similar trend in all bogs, appearing with the Abies-Picea decline and increasing gradually to the upper levels. Although represented by only a few pollen grains, Tsuga was found in all three bogs. Representation of hemlock in the Bacon's Swamp spectrum was limited to one pollen grain, found in the 12-foot level of boring III. Pinus was represented in all levels of boring III, but was most prominent in the levels above nine feet. A slight increase in Pinus frequency occurred in the 12-foot level, the point at which the Tsuga pollen grain was found. Rapid disintegration of Tsuga pollen when wet probably resulted in the virtual elimination of the genus from the pollen spectrum. Hemlock probably flourished during the period of pine prominence, much in the manner of the Michigan and Wisconsin subboreal forests, although this hypothesis cannot be proven from the fossil pollen analysis of Bacon's Swamp. This limited evidence is sufficient, however, to prove that Tsuga was represented in the forest succession of central Indiana.

The absence of pollen in the upper 12 levels of the Fox Prairie (17) bog prevented comparison of this portion of the spectrum with Bacon's Swamp. However, the Emporia bog (2) showed an interesting correlation with the upper ten levels of Bacon's Swamp. Quercus, having increased gradually from the time of appearance in the lower levels, decreased in frequency in the upper ten levels of both bogs. Carya, likewise, declined in this portion of the spectra. Juglans, Salix, Ulmus, and the Betula group dropped to the low-frequency classes. Acer and Fagus appeared about the 10-foot level and increased in frequency to the surface. Bacon's Swamp differed slightly from the Emporia bog in that these climax genera reached higher percentages at the surface, although the Acer-Fagus frequency curves were quite similar in the two bogs.

A comparison of the results from these central Indiana bogs with those of more distant bogs indicates that the forest stages after the glacier were quite general. Smith (21) reported results from the pollen analysis of Lake Cicott bog, in Cass county, which were similar to the findings in Bacon's Swamp. Abies and Picea controlled during deposition of the lower two levels of marl in Lake Cicott. The period of Abies-Picea dominance was much shorter, however, than in Bacon's Swamp, where the conifers controlled the spectrum throughout the lower 12 levels. This persistence of Abies and Picea in the lower levels of Bacon's Swamp seems to be characteristic in the southern bogs of Early Wisconsin glacial origin, for Barnett (2) and Prettyman (17) obtained similar results from bogs in Madison county and Hamilton county. The period of cool, moist climate which lasted for a time after glacial retreat, was evidently responsible for the Abies-Picea forest. This period must have continued much longer during retreat of the Early Wisconsin glacier than during the corresponding period following retreat of the Late Wisconsin substage. There is no vegetational evidence of a warm period between the two glacial advances which would have resulted in invasion of the conifers by a broad-leaved forest, followed by a return of conifers with the advance of the Late Wisconsin substage to within 60 miles of Bacon's Swamp. Malott (14) describes the retreat of the Early Wisconsin glacier as unsteady and marked by numerous recessions and readvances. Such a readvance resulted in the Late Wisconsin substage. A long period of glacial retreat and readvance in northern Indiana resulted in a prolonged period of cool, moist climate favorable to Abies-Picea control in the Bacon's Swamp region. However, the bogs formed by the Late Wisconsin substage show different results. Evidently, retreat of the substage was more rapid and consistent, resulting in a shorter period of climate favorable to the Abies-Picea forest.

A high representation of Pinus followed the rapid decrease of Abies and Picea in Lake Cicott. This phase of succession is quite different from results obtained in central Indiana, where Pinus never occupied a prominent position in the pollen spectrum. Quercus and Carya appeared in Lake Cicott immediately following Pinus, and remained dominant to the surface level. The characteristic decrease of Quercus and Carya pollen in the surface levels of the southern bogs was not found in Lake Cicott. The absence of a period of Pinus prominence immediately following Abies-Picea retreat in the Bacon's Swamp region is probably due to a rapid warming up of the climate with considerable moisture still present. These climatic conditions favored the rapid increase to dominance of Quercus rather than Pinus and Carya. A warm, moist climate during this period is further evidenced by the increase of Salix, Populus, Larix, and the Betulaceæ. The warm, dry period favoring Pinus and Carya increases did not occur until the time represented by the 12-foot level in boring IV of Bacon's Swamp. Had the climate in central Indiana become dry as well as warm, following the cool, moist period, Pinus, and perhaps Carya, would have been prominent in the spectrum prior to the advances of the mesophytic broad-leaved forest, much in the manner of the Lake Cicott area. A further explanation for absence of the early period of Pinus prominence is the lack of sandy soil and hills in the Bacon's Swamp region. The flat, relatively low ground favored Quercus rather than Pinus as an early invader of the Abies-Picea forest.

Another difference in the upper levels of Lake Cicott bog was the low representation of Acer and Fagus pollen. Smith's results are quite similar to those obtained by Sears (19) in Bucyrus bog, who describes a period of Pinus prominence immediately following the disappearance of Abies and Picea from the spectrum, and preceding the rapid increase of Quercus and Carya. Houdek (13) found an Abies-Picea-Pinus-Quercus succession in Center Lake bog, near Gary, Indiana. Voss (22) also mentions Pinus as a dominant species following Abies and Picea in the successional stages of a northern Illinois bog.

Vegetation is an expression of climatic conditions. Gleason (12) states: "Migration of a species depends upon an environmental change in or beyond its range." The vast changes in the forest content of Indiana since glacial recession, as evidenced by the pollen spectrum of boring IV in Bacon's Swamp, indicate, therefore, corresponding changes in the climatic conditions of the region. With the retreat of the Early Wisconsin ice sheet, vegetational succession on the newly exposed land was initiated. The boreal forests which were driven south by the moving glacier are thought by Gleason (12) to have occupied a narrow strip between the ice sheet and the broad-leaved forest to the south. There is a question as to the existence of a tundra stage in the immediate vicinity of the melting ice during recession of the glacier. No microscopic evidence of a tundra was found in Bacon's Swamp, although such tundra plants could well have existed and disappeared before marl deposition in the lake began. Cooper (6) does not mention a tundra stage preceding the Abies-Picea forest in Glacier Bay, Alaska. Gleason (12), on the other hand, is of the opinion that a tundra stage did exist near the ice sheet on the newly exposed land formed during glacial recession. He believes also that rock barriers now supporting boreal relicts in mesophytic forest areas once harbored tundra relicts. If a tundra stage existed, the advancing Abies-Picea forest soon grew over it, for Cooper (6) describes the advance of the coniferous forest "on the heels of the retreating glaciers in Alaska." No doubt a similar condition existed in Indiana. Abies and Picea thrived in the cold soil resulting from glacial waters, but indications are that a tundra could hardly have existed under these conditions.

The persistence of the Abies-Picea forest through the period of deposition of 12 feet of marl and peat in Bacon's Swamp indicates a cool, moist climate. Gleason (12) states that, with glacial retreat, the narrow strip of coniferous forest broadened out to cover the newly exposed land. He believes, also, that the northward advance of the conifers was much more rapid than the southern retreat, resulting in time in an extensive coniferous forest. The presence of such a forest is evidence of a direct effect of the glacier on the climate of the adjacent regions. Perhaps the winds blowing across the ice sheet lowered the temperature of the region south of the glacier considerably, even though the general climate of the section might have been much like the present. Another factor contributing favorable conditions for the coniferous forest was the continued presence of icy waters flowing from the glacier. The width of the river beds in central Indiana are evidence of the size of these glacial streams. Numerous other streams, now extinct, no doubt also penetrated extensive areas south of the glacier. The general lowering of soil temperature and abundance of moisture and frost in the soil as a result of these icy waters, produced conditions favorable to an Abies-Picea forest and prevented invasion of the area by broad-leaved species for a considerable period of time.

The pollen spectrum of boring IV indicates a gradual decline of Abies and Picea frequencies during the period represented in the lower 12 levels of the bog. At the time of deposition of levels 19 and 20, an interesting change occurred in the forest. Abies dropped suddenly from a pollen frequency of 40 percent in the 21-foot level to 2.5 percent in the 19-foot level. This rapid decline of Abies was followed closely by a similar decrease in the Picea pollen frequency. The recession of the conifers was accompanied by a sudden increase in the frequency of broad-leaved species. Quercus, Salix, Juglans, Ulmus, and the Betulaceæ are shown to have invaded the Abies-Picea forest. This sudden change in the pollen spectrum suggests a climatic change in the region. The retreat of conifers and advance of the broad-leaved forest indicates a change from cool, moist conditions to a warmer, perhaps drier, climate. If the ice sheet and cold glacial waters in the soil were largely responsible for conditions favoring Abies and Picea, the recession of the glacier and resultant increase in temperature and drying out of the soil would mark the end of this coniferous forest. In the time required for deposition of 12 feet of marl and peat in Bacon's Swamp, the ice sheet could have melted to a point considerably north of the bog. Removal of the ice sheet and changes in river courses carrying the glacial waters might well have altered the climate in the Bacon's Swamp area. This warm, somewhat drier period was marked by a rapid increase of Quercus. Carya increased gradually but did not reach high frequencies in the pollen spectrum. Betula also came into the spectrum in the low frequency classes. Quercus and Carya probably invaded the upland coniferous forest, while Juglans, Populus, Salix, and Ulmus came into the lowlands. Larix also shows a rapid pollen frequency increase at the 20-foot level, further indicating subboreal conditions. Local factors around the lake, such as formation of the Sphagnum mat, were no doubt also responsible for this Larix increase.

Another climatic change is indicated in the pollen frequencies of the 11-, 12-, and 13-foot levels of boring IV. Pinus and Carya show a sudden increase, while Betula, Salix, Populus, and Larix drop to the low frequency classes. The abundance of Pinus and Carya at this point in the spectrum indicates a period of increased dryness. The disappearance of Abies and Picea in these levels further suggests increased dryness and warmth.

Still another climatic change is evidenced during the formation of the upper ten levels. Acer pollen appeared in the spectrum in the 14-foot level and increased in frequency to 22 percent in the 1-foot level. Fagus pollen was first found in the 9-foot level and increased to 12 percent at the 1-foot level. This introduction of mesophytic climax species in the upper ten levels is an indication of a warm, moist climate. The increase in moisture at this time is further shown by the decline of Carya pollen from 27 percent in the 9-foot level to 8 percent at the 1-foot level. Acer and Fagus no doubt invaded the lowlands, while Quercus and Carya were prominent in the upland regions. Pine pollen remained in the spectrum to the 1-foot level, but showed no tendency to increase after its sudden drop in the 11-foot level. Juglans increased in the upper ten levels, while Ulmus showed a gradual decline. The mesophytic period is marked also by the absence of Betula, Alnus, and Corylus, and the scarcity of Larix pollen. Thuja appeared in the spectrum during this period. The Thuja frequencies are not representative, however, because of the decomposition of the pollen when wet (Sears, 18).

The absence of Fraxinus pollen from the spectrum during dominance of broad-leaved species is difficult to explain. It is a prominent secondary species in the modern forests of Indiana. Fraxinus was represented by a few pollen grains in the 11-, 13-, and 14-foot levels, but was not found in the peat above that point.

In general, the period of increased moisture represented in levels 1-10 of the bog spectrum marked the increase of mesophytic genera. Acer and Fagus invaded the moist situations. Quercus probably remained dominant in the uplands and possibly invaded the lowlands, while Ulmus, Juglans, Salix, and Populus remained as secondary species in the lowlands. Carya, Pinus, and the Betulaceæ decreased, and Abies and Picea dropped out of the spectrum.

The migration of forests as shown in the pollen analysis of boring IV indicates a series of climatic changes. These periods, in chronological order are: first, a cool, moist climate dominated by Abies and Picea; second, a warmer and drier period, marked by a rapid decrease of the conifers and increase of the frequency of broad-leaved species dominated by Quercus. The third period, suggested by the rapid increase of Pinus and Carya and the decrease of Larix, Populus, and Salix, appears to have been even more dry. Evidence of such a period was found in the pollen content of the 11-, 12-, and 13-foot levels. A final period of increased moisture is marked by the rapid increase of Acer and Fagus pollen in the upper ten levels, and a corresponding decrease of Carya and Pinus pollen frequencies.

The climatic periods are similar to those described by Sears (20). However, the Bacon's Swamp results differed from Sears' results in the absence of a dry, cool period dominated by Pinus between the Abies-Picea forest and the invasion of the conifers by broad-leaved species. The migration of forests through central Indiana since Pleistocene times indicates ever-changing environmental conditions. This succession will probably never cease, since temperature and moisture conditions never become fixed in a specific region. Climatic changes result in migration of the vegetation. To use the word of Gleason (12), "Both advancing and retreating migrations are now in progress in the Middle West."

Comparison of the pollen frequency curves of borings III and IV revealed an interesting correlation between the two spectra. The reliability of the analysis of fossil pollen in peat as a means of determining past forest succession is further demonstrated in the results. Chance distribution of pollen grains on the active peat mats in the bog would naturally result in some variations in the pollen frequency curves of the two borings. However, considering that only a small amount of peat was mounted on a slide for examination and that the borings were made in opposite ends of the bog, the correlation of results shown in figure 2 is very striking.

The Abies-Picea frequencies in the first foot of marl deposited at the locations of the borings bear a marked similarity, showing a variation of only 2 percent in content of Picea pollen and 4 percent in Abies, indicating that marl deposition was instituted at about the same time in the region of both borings. The small difference might well be attributed to chance distribution of pollen on the mat. Further similarity is shown in the rate of increase of Picea and the gradual decline of Abies from that point in the spectrum. Both borings show also a rapid drop in frequency of Abies and Picea pollen following the period of dominance. While the decline is similar in the two borings, figure 2 shows that the rapid decrease occurred approximately four or five foot-levels later in boring IV than in III. The frequency curves which had compared closely in the lower seven levels of both borings became separated by about five foot-levels prior to the decline of the conifers in boring IV. Figure 2 shows that Abies and Picea pollen in boring IV failed to decline with the spectrum curves of boring III. High frequency of coniferous pollen was found in approximately five levels after the rapid drop in boring III. The period of Abies-Picea dominance is recorded in seven levels of boring III, while boring IV represented the same period in 12 levels of marl and peat. Furthermore, the correlation of frequencies in the lower seven levels of both borings and above the 12-foot level of boring IV definitely locates the five feet of deposition which contains the portion of the spectrum not represented in boring III. It is interesting to note that after this separation of the spectra curves between levels 20 and 25 in boring IV, deposition of peat occurred at about the same rate in both borings. The lines showing rapid recession of Abies and Picea are parallel, and the points of disappearance of the conifers from the spectrum are separated by approximately five foot-levels. Evidently, for some reason, during the period of deposition of one foot of marl in boring III just prior to the Abies-Picea decline, five feet of marl and peat were formed in boring IV, hence the separation of the frequency curves above that point in the bog by approximately five foot-levels. The reason for this more rapid deposition of peat and marl in boring IV during this period is uncertain. Perhaps a washing-in of deposited marl from other parts of the lake or an abundance of Chara or other marl-forming plants in the deep end may have been responsible.

Evidence of more rapid deposition of approximately five feet of marl and peat in boring IV while one foot was being formed in boring III is further shown in the separation of the frequency curves of Quercus, Carya, and Larix. Pinus showed such a fluctuation in percentages that comparison of frequencies in the two borings is difficult. However, the frequency curves of the other genera run consistently above the corresponding curves of boring III. These results of boring IV indicate also that after the period of more rapid peat and marl deposition in boring IV as compared with boring III, peat was formed in both ends of the bog at about the same rate.

Assuming that deposition did occur at the same rate in borings III and IV, the shallower region of the lake in which boring III was made would have filled sooner than the deeper end in the region of boring IV. Pollen grains are preserved only on active peat mats (Erdtman, 8). Therefore, the filling of the shallower end, resulting in the drying out

TABLE I

POLLEN PERCENTAGES — BACON'S SWAMP

Results of boring III are given on the upper line and boring IV on the lower for each foot-level, except from the 23rd through the 32nd foot-level the figures are for the fourth boring only.

Foot Level	Abies	Larix	Picea	Pinus	Thuja	Tsuga	Acer	Alnus	Betula	Corylus	Carya	Fagus	Fraxinus	Juglans	Populus	Quercus	Salix	Tilia	Ulmus
1	—	3	—	9	—	—	11	—	—	—	15	2	—	6	4	36	2	—	12
	—	—	—	6	—	—	22	—	—	—	8	12	—	5	3	31	4	2	7
2	—	6	—	9	—	—	9	—	—	—	14	4	—	5	5	37	8	—	3
	—	—	—	6	—	—	23	—	—	—	17	13	—	5	2	28	2	—	4
3	—	5	—	7	—	—	9	—	—	—	24	—	—	4	4	38	2	—	7
	—	1	—	10	2	—	23	—	—	—	10	13	—	4	4	28	—	—	2
4	—	6	—	5	—	—	6	2	1	3	21	—	—	8	2	37	2	—	7
	—	4	—	8	4	—	20	—	—	—	17	7	—	5	4	26	2	—	3
5	—	7	—	3	½	—	5	1½	1½	1	21½	—	—	10	2	36	2½	—	8½
	—	—	—	6	—	—	17	—	—	—	16	12	—	4	6	30	2	—	6
6	—	8	—	4½	—	—	3½	1	½	1	22	—	½	3	4½	36	2½	1½	12
	—	—	—	4	3	—	16	—	—	—	17	4	—	10	6	28	3	—	5
7	—	7	—	7	1	—	2	1½	3	3	19	—	—	3½	3½	32½	2	—	15
	—	—	—	4	3	—	15	—	—	1	17	2	—	7	—	36	3	1	12
8	—	4½	½	6½	—	—	2½	2	1½	2½	16½	—	—	3½	2½	35½	2	1	19
	—	1	—	6	—	—	12	1	—	—	20	1	—	5	—	34	4	—	16
9	5½	24	4	6½	1	—	1½	2	1½	2½	7	—	1	1½	3½	22½	3½	½	11
	—	1½	—	4	—	—	13½	½	½	—	27	—	—	½	½	38	2	1	10½
10	3	17½	5	3½	1	—	½	7	5½	2½	5½	—	—	2½	—	26	13	½	7
	—	1½	—	3	2½	—	10½	—	—	1½	25½	—	—	3	—	35½	½	—	14½
11	4½	20	5½	2	1	—	—	5	2½	2½	6½	—	—	1	—	24	17½	—	8
	—	2	1½	4½	3	—	7½	1	—	½	27½	—	1	—	—	34	1	—	17
12	7	14½	10½	3½	—	½	—	1	6½	4	8	—	—	—	—	19½	21	—	4
	4	15½	12½	23½	1½	—	3½	3	2½	3	6	—	—	½	½	17	3½	1½	7
13	10	21	27½	1½	—	—	—	—	3	2	8	—	—	—	—	13	9½	—	4½
	2½	19	9	8	1½	—	1	5½	2	2½	8	—	2	—	—	25	4	½	10½
14	32	15	40	2	—	—	—	—	2	½	—	—	—	½	—	8	—	—	—
	2½	21	4½	1	1½	—	2½	3½	4	2½	6½	—	2	—	½	29	5½	—	12½
15	38½	7	52½	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
	—	29½	3	½	—	—	—	3½	5½	5	4	—	—	½	—	26½	9½	—	11½
16	44	—	54	2	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
	½	32½	3	1	—	—	—	1½	7½	2	5	—	—	1	½	26	15	—	4
17	37	—	60	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2½	19½	10	2	—	—	—	4	3½	2	4	—	—	2½	2½	22½	18	—	7
18	47	—	52	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1	18½	11	½	—	—	—	7	10½	2½	2	—	—	4	½	19	16	1	6½
19	46	1	49	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2½	14	22	5	—	—	—	3½	12½	1½	2½	—	—	2	—	18½	16	—	1
20	52	—	44	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	10	48	3½	—	—	—	2½	3	½	½	—	—	—	—	1½	4½	—	—
21	54	—	42	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	40	3	51	½	—	—	—	½	½	—	2	—	—	½	—	1½	—	—	—
22	58	—	40	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	41	2	50	1	—	—	—	—	½	—	½	—	—	—	—	1	5	—	—
23	40½	3½	45	3	—	—	—	—	1	—	1	—	—	—	—	1½	3	—	—
24	46	—	50	2	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
25	48	—	47	1	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
26	47	—	50	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
27	45	—	54	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	43	½	55	1½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	50	1½	47	1½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	56	½	43½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	60	½	39½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	62	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

of the Sphagnum mat, ended the pollen spectrum of boring III. The mat in the deeper end remained active longer and therefore continued the pollen spectrum beyond the end of boring III. This hypothesis is borne out, also, in the Acer-Fagus comparison. These genera, prominent in the upper levels of boring IV, are represented by much lower frequencies in boring III. Only the 1- and 2-foot levels of boring III contained Fagus pollen, while boring IV showed Fagus pollen in eight levels. The greatest frequency of Fagus in boring III was 4 percent, as compared with a frequency of 12 percent in the 1-foot level of boring IV. Acer pollen, although present in ten foot-levels in boring III reached only 11 percent in frequency at the 1-foot level, while it occurred in 14 levels in boring IV and reached a frequency of 22 percent. This comparison indicates that the pollen spectrum of boring III is not complete, the period of Acer-Fagus prominence shown in the upper levels of boring IV not being represented.

In general, the comparison shown in figure 2 illustrates several interesting facts. The close correlation of the pollen frequency curves shows the relatively even distribution of pollen over the surface of a bog. The similarity of results in the two borings further indicates the reliability of fossil pollen analysis as a method of determining past forest succession. Also, the absence of the upper portion of the spectrum of boring IV from the more shallow boring, suggests that the deepest part of a lake supports an active Sphagnum mat longest. Therefore, the most complete pollen spectrum should be obtained from analysis of a boring made in the deepest part of a bog.

SUMMARY

1. Bacon's Swamp is unique in its location near the southern border of Early Wisconsin glaciation.

2. Two borings made in opposite ends of the bog were analyzed for fossil pollen content of the marl and peat deposits.

3. Results showed a succession of forests from an early postglacial Abies-Picea control to the present Acer-Fagus-Quercus mesophytic climax.

4. Abies and Picea controlled during the period of deposition of the lower 12 levels of boring IV.

5. At the time of deposition of the 20-foot level, the conifers dropped suddenly and broad-leaved genera dominated by Quercus assumed control of the pollen spectrum.

6. Levels 11, 12, and 13 marked a period of rapid increase of Carya, Quercus, and Pinus, and a decrease of Ulmus, Salix, Populus, and the Betulaceæ.

7. The upper ten levels of boring IV marked the appearance of Acer and Fagus pollen in the spectrum, and an increase in frequency to a position of dominance. Carya declined rapidly, and Quercus showed a slight decrease.

8. Results were similar to those of other bogs in the region.

9. The forest succession suggests the following climatic periods: cool moist, moderate dry, warm with increased dryness, and warm moist.

10. A comparison of the spectra of borings III and IV shows a close correlation of results. Although the frequency curves paralleled in the lower seven levels of both borings, they were separated consistently by five foot-layers above the 12-foot level of boring IV.

11. The period of Acer-Fagus prominence shown in the upper ten levels of boring IV is absent in boring III, indicating that the pollen spectrum of boring III is not complete because of earlier filling-in of the shallower part of the lake.

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THE FOSSIL POLLEN OF KOKOMO BOG, HOWARD COUNTY, INDIANA[1]

By JOHN W. HOWELL

Study of fossil pollen is recognized as a key to the understanding of past and present-day vegetations, especially in the northern extensions of the broad-leaved forest. For several years the Botany Department of Butler University has conducted fossil pollen studies in an effort to decipher the vegetational history of the state of Indiana since Pleistocene time. According to Friesner (4), Indiana is a critical botanical area, and marks within its boundaries the northern limits of southern species and the southern limits of northern species, and so offers splendid opportunities to study migrations of vegetations. Previous work in fossil pollen analysis has shown that Indiana once had a uniform simple boreal forest made up of spruce and fir. The present-day climax associations invaded and crowded out the conifers. But even today one may see relic colonies of various boreal plants scattered throughout Indiana, especially in the northern counties, as remnants of what was once a vast coniferous forest (Welch, 18). This study is concerned only with tree and shrub pollen, because trees and shrubs form the dominant vegetation in this area, and, as Godwin (7) says, trees and shrubs also aid in the interpretation of past climates.

The bog here under study is located northeast of Kokomo, on the farms of Messrs. C. E. Marvin and Willis. It forms a large oval, with its long axis running in a northeast-southwest direction and is one-half mile long and one-fourth of a mile wide.

Howard county, in which the Kokomo bog is located, lies 46 miles north of Indianapolis and is situated in the north central part of Indiana. The surface is level, with scarcely any perceptible undulation, and presents characteristically the undisturbed level of the glacial drift. The soil was originally a rich black muck, since changed by drainage and sunshine into a light loam of great fertility.

DESCRIPTION AND PRESENT-DAY VEGETATION

Kokomo bog is of the kettle hole type associated either with moraines or with outwash plains. During the melting and recession of a glacier, large masses of ice sometimes became separated from the main body of the glacier due to differential melting, and subsequently were buried under succeeding deposits of moraine or outwash materials. These fragments melt, and, as they do so, the overlying materials gradually fill in the cavity, forming a surface depression. Water may then collect in these so-called kettle holes, producing an open lake. The encroachment of mat-forming plants upon the lake may completely fill the depression with decomposed organic matter, and the lake is thus transformed into a bog.

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[1] This paper is a portion of a thesis in parital fulfillment of the requirements for the degree of Master of Arts in Butler University.

The rate of growth of peat deposits has been variously estimated. It is quite obvious that the time required to form a foot of peat depends upon the depth in the peat profile at which the foot is taken. Sears (13) suggests an average of 25 years to the inch. Such a figure would mean that approximately 10,000 years were required to form the peat found in the Kokomo bog.

A narrow wooded section runs across the center of the bog in a north-south direction. Sphagnum is still growing about clumps of Rosa, Spiræa, and other shrubs. The following plants commonly found in bogs have recently been collected from this bog: *Dryopteris cristata, Ilex verticillata, Aster umbellatus, Eupatorium perfoliatum, Osmunda cinnamomea, Dryopteris thelypteris pubescens, Spiræa tomentosa, Osmunda regalis, Solidago serotina, Rosa palustris, Mimulus ringens, Ludvigia palustris,* and *Betula pumila.* The finding of *Betula pumila* in Howard county has set a new southern limit for this species in Indiana. Other plants found were: *Solidago hirtella, Acer saccharinum, Ulmus americana, Cornus obliqua, Phytolocca americana, Bidens coronata, Scirpus cyperinus, Lycopus virginicus, Rubus hispidus, Verbena urticæfolia, Muhlenbergia foliosa, Veronica scutellata, Bidens comosa.*

METHODS

The peat borer used was of the hollow cylinder type, surrounded by a movable sleeve with a cutting edge at the opening. It can be closed by reverse turning of the handle after the core has been cut, thus preventing contamination of the sample as the borer is removed. The cylinder was thoroughly washed after removal of each sample of peat. Samples were taken at every foot-level until the borer encountered sand at the 32-foot level, which was considered the old lake bottom. The samples of peat were taken from the central section of the core, and placed into bottles, stoppered tightly, and labeled as to bog location and depth in feet. Two borings were made, one on the east and one on the west margin of the present wooded belt. Boring A showed 12 feet of marl and 21 feet of peat. Boring B showed 12 feet of marl and 20 feet of peat.

The preparation of peat for microscopical identification was carried out according to the method used by Geisler (5). Excellent results were obtained. In strata like the lower marl and the upper four feet of peat, where the pollen frequency was very low, a much larger sample of peat was used to obtain better pollen frequency. This also required more stain than the amount suggested by Geisler. Gentian violet proved to be a satisfactory stain for all levels.

A binocular microscope equipped with 15X oculars, 43X objective, and a graduated mechanical stage was used for examination of the pollen. Prepared slides of modern pollen and diagrams from Sears (14) and Wodehouse (19) were compared with the fossil grains for purposes of identification.

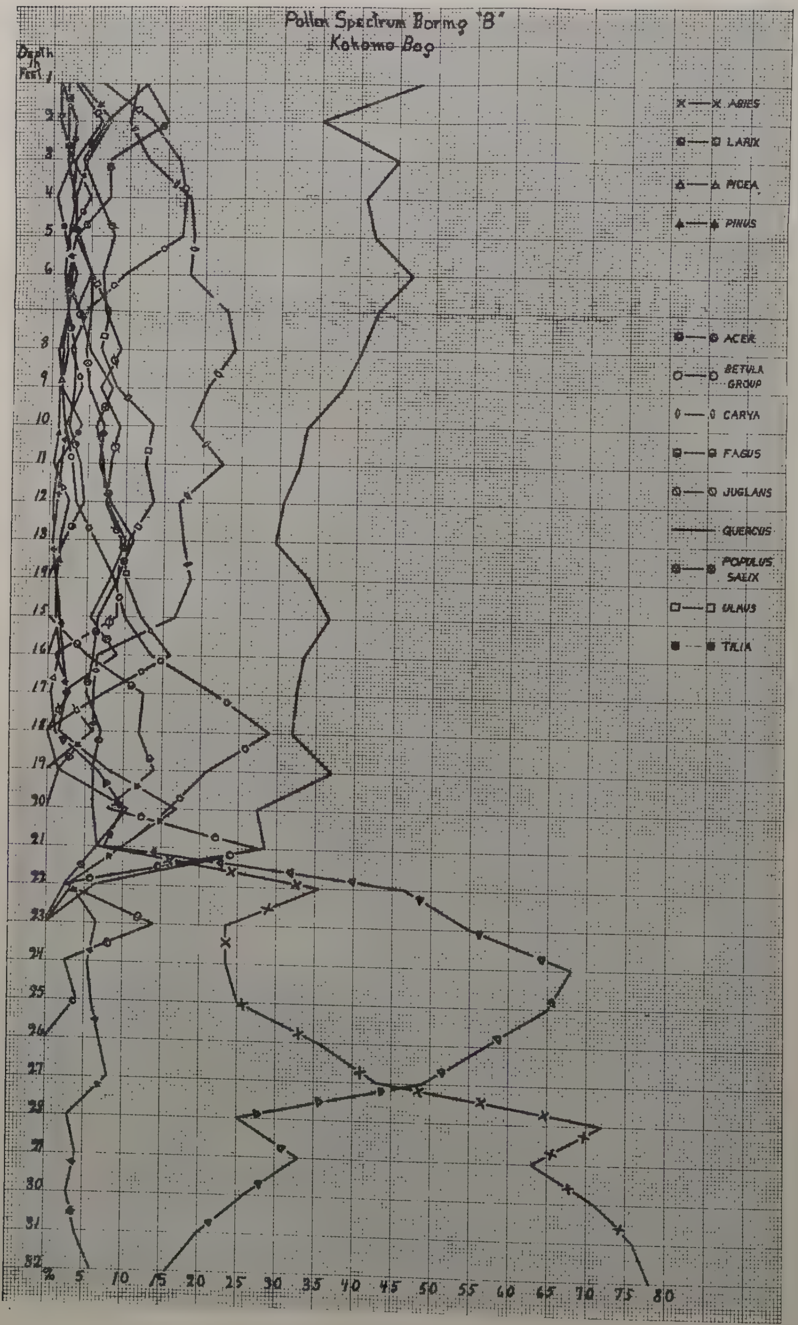
Since only a few genera were represented in the lower five feet of marl and pollen was sparse, only 100 grains were counted in these levels, but for all other levels 200 grains were used.

OBSERVATIONS

Acidity is an edaphic factor which is very important in plant distribution, and, while the present work did not concern itself with plants in relation to habitat, it seemed well to determine the acidity of the various layers of peat as a secondary study easily made without additional labor to obtain samples. Kokomo bog showed a tendency to become alkaline in the lower levels, as has been found to be true in other Indiana bogs studied (Potzger, 10; Barnett, 2; Smith, 17). The active acidity for every foot-level was determined with the Youden hydrogen-ion apparatus. Acidity was slight at the 1-foot level (pH 6.31). From the second to the 8-foot level acidity increased (pH 5.73), but from the 9-foot level to the bottom of the bog there was a gradual decrease in acidity. An alkaline reaction was first observed at the 28-foot level (pH 7.03). This alkalinity increased until it reached pH 7.43 at the 32-foot level.

The peat found in boring A was of the same nature as that in boring B. Due to their similarity, only the results of boring B are shown in figure 1. The peat found in the upper 16-foot levels was of a chocolate brown color, but at the 17-foot level it changed to a dark black color. Marl of a grayish appearance occurred at the 20-foot level and con-

FIGURE 1


Pollen Spectrum Boring "B"
Kokomo Bog
Depth in Feet
1
2
3
4
5
6
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
%
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
ABIES
LARIX
PICEA
PINUS
ACER
BETULA GROUP
CARYA
FAGUS
JUGLANS
QUERCUS
POPULUS SALIX
ULMUS
TILIA

tinued to the bottom. It was noticed that, as the depth of the bog increased, the finer became the particles of peat.

It will be noticed from figure 1 and table I that Abies and Picea control the bog from the 32- to the 22-foot level. Quercus makes its appearance at the 22-foot level, becomes dominant at the 20-foot level, and continues to control the spectrum from this point to the surface. Carya appears at the 18-foot level and forms an association with Quercus not to be broken until Betula surpasses it at the 4-foot level.

Abies drops out at the 18-foot level, while Picea persists by a very small percentage to the 6-foot level. Picea persists in the Kokomo bog to nearer the surface than in any of the bogs thus far studied in the Early Wisconsin drift. Pinus is the only genus found throughout the entire spectrum. It is represented in the main by small percentages, but reaches 10 and 17 percent respectively at the 21- and 20-foot level in boring B, and 15 percent at the 18-foot level in boring A. Larix occurs at the 25- to the 16-foot level in boring B, and at the 21- to the 12-foot level in boring A.

Ulmus and Juglans form a secondary climax. The former occurs from the 17-foot level to the surface in boring B, and from the 20-foot level to the top in boring A, while the latter occurs from the 17-foot level to the surface in both borings. Acer never gains a prominent position, but persists from the 19-foot level to the surface in both borings. Salix is found only in small numbers from the 22-foot level in boring B and the 20-foot level in boring A to the surface. Populus percentages were similar to Salix. However, Populus makes its appearance much later than Salix in 17- and 16-foot levels.

The results from the two borings were very similar; possibly due to the very slight difference in depth. The only noticeable difference occurred at the lower levels, where there was a greater degree of fluctuation between Abies and Picea.

DISCUSSION

While the study of soil acidity, as previously stated, was not the primary importance of this investigation, it is thought worth while to attempt to explain the results obtained. The study of plants and their relationship to acidity has been the source of extensive investigation on the part of many investigators, and it is believed that there is a definite correlation between them.

The alkalinity of the lower levels of Kokomo bog is probably not

TABLE I

POLLEN PERCENTAGES — KOKOMO BOG

Results of boring A are given on the upper line and boring B on the lower line for each foot-level.

Foot Level	Abies	Picea	Pinus	Larix	Acer	Alnus	Betula	Corylus	Carya	Fagus	Juglans	Populus	Quercus	Salix	Tilia	Ulmus
1	—	—	2½	—	3	—	7½	—	12	2	5	9½	45	4	2½	5
	—	—	3½	—	2	—	6½	—	11	1	12	7	48	5	1	3
2	—	—	4	—	3	—	11½	—	8½	5	8½	13	33½	3½	3	5
	—	—	7½	—	2	—	13	—	10	3	7	10	35	5	1	6½
3	—	—	3½	—	4	—	14	—	12½	4	5½	4	40½	2½	1½	5½
	—	—	4½	—	2	—	16½	—	12½	2½	4	5	45	2½	2½	3
4	—	—	2	—	2	—	19½	—	10	3½	5½	1½	43½	2½	1½	7
	—	—	3	—	3	—	17½	—	12½	5	6	2½	41	5	½	2½
5	—	—	1½	—	5	—	12	—	16½	3	5½	4½	45½	1½	1	2
	—	—	2	—	3	—	17	—	19	1	8	2	42	2	1½	3½
6	—	1	3	—	4½	—	6½	—	18½	2½	8	4	42	2	4	1½
	—	—	2½	—	2	—	9½	—	18½	1½	6½	3½	47	1½	2½	5
7	—	1	1½	—	4½	—	5	—	25½	1½	7½	1½	43	1	1	6
	—	½	2	—	3½	—	4½	—	23½	2	7	3½	42½	1½	2	7½
8	—	1½	2	—	3	—	4½	—	22½	4½	9½	4	37	1½	3½	6½
	—	1½	1	—	5	—	2½	—	24	3	9	2	40½	2½	2	6½
9	—	2	1	—	4½	—	8	—	23½	2	7½	1½	35	2½	1	10½
	—	1	1½	—	8	—	2½	½	20½	3	6½	3½	30	1½	1½	8½
10	—	½	1	—	5	—	3½	—	17	4	10½	7	32½	2	5	10½
	—	1	2	—	6	—	2	—	18½	2½	9	3½	33½	3½	4	13½
11	—	1½	½	—	3½	—	2½	—	20	5	7½	5½	35	3½	3	12½
	—	½	1½	—	7	—	3	½	22½	4	8	4	32½	2½	1½	12½
12	—	1½	2½	½	5	—	4½	—	20½	4½	7½	5	30	4½	1½	12½
	—	2½	1	—	7½	—	3½	—	17	4½	7½	5½	30½	2½	½	13½
13	—	½	1½	2	5½	2	9	—	18	2	7½	7	32	3	1	10
	—	1½	½	—	10	—	5	1	17½	2	9½	8	29½	3	½	10½
14	—	½	1½	½	4	3	7	—	20½	1½	7½	3½	35½	5½	2	7½
	—	1	1	—	8	1½	5½	1½	18½	—	9	2½	34	6½	1	10
15	—	1½	2	3	3	2½	5½	—	18	—	7½	3	35	3	1	15
	—	1	1½	—	5½	2½	7	1	16½	—	9	1½	36	5	1½	12
16	—	1	1	8	2½	1½	11	2	15	—	4	4½	33	2	1½	12½
	—	1½	2	5	9	½	9½	3½	11½	—	1	2½	33½	3½	—	16
17	½	1½	3	13½	1½	3	14	3½	13	—	1½	2	31	3½	—	8½
	—	½	2½	12½	2	4	13½	5	11	—	3	—	32½	5	—	7½
18	2	5	15	9½	4	3	10	3	5	—	—	—	27	5	—	11
	—	1	1½	12	5½	8½	16½	4	11	—	—	—	32	7	—	—
19	1	5	8	10	3	—	12	1½	4	—	—	—	32½	9½	—	13
	1½	6½	8½	14	1½	6	10½	4½	—	—	—	—	37	6	1½	—
20	7½	5	5½	24	—	2½	15	3	—	—	—	—	33½	2½	—	1
	10½	10	17	8	—	4	11	1	—	—	—	2	27½	6	—	—
21	24½	42	9½	10½	—	—	4	—	—	—	—	—	9½	—	—	—
	6½	7½	10	28	—	—	10	—	—	—	—	½	28½	6½	—	—
22	33	58	5	—	—	—	1	—	—	—	—	—	2	—	—	—
	35½	46½	3½	2½	—	—	3½	—	—	—	—	—	6½	2½	—	—
23	31	62½	6½	—	—	—	—	—	—	—	—	—	—	—	—	—
	23½	55	6½	14	—	—	—	—	—	—	—	—	—	—	—	—
24	35½	61	3½	—	—	—	—	—	—	—	—	—	—	—	—	—
	23½	68	5½	2½	—	—	—	—	—	—	—	—	—	—	—	—
25	33½	62	4½	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	65	6	4	—	—	—	—	—	—	—	—	—	—	—	—
26	48½	49½	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	35½	57	7	—	—	—	—	—	—	—	—	—	—	—	—	—
27	58	39	3	—	—	—	—	—	—	—	—	—	—	—	—	—
	43	49	8	—	—	—	—	—	—	—	—	—	—	—	—	—
28	58	37	4	—	—	—	—	—	—	—	—	—	—	—	—	—
	72	25	3	—	—	—	—	—	—	—	—	—	—	—	—	—
29	63	35	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	63	33	4	—	—	—	—	—	—	—	—	—	—	—	—	—
30	68	29	3	—	—	—	—	—	—	—	—	—	—	—	—	—
	71	26	3	—	—	—	—	—	—	—	—	—	—	—	—	—
31	66	25	9	—	—	—	—	—	—	—	—	—	—	—	—	—
	76	20	4	—	—	—	—	—	—	—	—	—	—	—	—	—
32	58	34	8	—	—	—	—	—	—	—	—	—	—	—	—	—
	78	16	6	—	—	—	—	—	—	—	—	—	—	—	—	—
33	73	16	8	—	—	—	—	—	—	—	—	—	—	—	—	—

Tsuga—½% at 21-foot level of boring B; ½% at 19-foot level of boring B.

indicative of the conditions when the forests grew there. The alkaline condition which is now present in the lower levels of peat of Kokomo bog, and others of similar nature as well, was probably caused by an upward movement of water which carried with it dissolved calcium carbonate. This movement would tend to render the peat less acid. However, today there are cases where such trees as Larix, Abies, and Picea (12) are found growing in alkaline soil. It would, then, be incorrect to say that the boreal type forest is always associated with an acid soil. There is also the presence of available water which should be taken into consideration. The outstanding factor that determines the relationship of plants to their environment may be the amount of available water present instead of the active acidity.

From personal observations of the forests of northern Michigan, it was noticed that Abies and Picea grew on the surface of the bogs. Such broad-leaved trees as Quercus and Carya were not found growing on these bogs. If one were to apply these observations to Kokomo bog, the answer would be that the various broad-leaved trees grew in the immediate vicinity of the bog and their pollen drifted over the surface of the mat. On many of the bogs of northern Michigan, the coniferous trees growing there were so dense that the broad-leaved trees would not have been able to compete with them. One cannot definitely say then as to the type of forest present on Kokomo bog at the time of the appearance of Quercus along with other broad-leaved genera. No evidence of Thuja pollen was found, but there is a possibility of a Thuja climax to the boreal forest present in the bog up to and even after the appearance of Quercus. Thuja is found today in bogs located farther south than Kokomo bog, even to the extent that it is the dominant species (Markle, 8). Thuja pollen is not able to withstand water (Sears, 14), and so could have deteriorated leaving no evidence of its former presence. Tsuga pollen also may have deteriorated. Tsuga today has a very scattered distribution, and such a condition may have existed centuries ago. Only two pollen grains of Tsuga were found, one at the 21- the other at the 19-foot level.

It is believed that plants are climatic indicators, and to the extent that they are we can say that in the region of Howard county a cool climate prevailed over a prolonged period of time, during the early developmental stages of Kokomo bog. A typical boreal forest of Abies and Picea existed at that time, which, according to Sears (13), indicates a cool, humid climate. At the 22-foot level the first evidences of deciduous trees appear, becoming dominant at the 20-foot level. Quercus is the dominant genus at this level, and its presence together with Carya suggests a warmer, drier climate. Quercus and Carya were the dominant climax species of the bog from the 21-foot level to the surface. A similar plant succession was found in such bogs as Bucyrus bog (15), Cranberry pond (2), Lake Cicott (17), Mud Lake bog (16). The rapid disappearance of Abies and Picea from the bog is difficult to explain. However, it is possible that after the glacier had retreated farther north, the cold seepage water formerly flowing over this area was drained off in some other direction, possibly via the Wabash river system. After the glaciers had retreated to the northern part of the state, Abies and Picea, thus deprived of their final climatic requirement, *i. e.*, cool soil, failed to continue their reproduction, and, as the old trees died, it spelled an end to these two genera.

The presence of Pinus pollen throughout the entire spectrum can possibly be explained on the basis that it was a relic near Kokomo and capable of withstanding a climatic change from a cool, humid to a warmer, drier condition. This is probable, in view of the fact that it is represented by small percentages except in the 21- and 20-foot levels in boring B and the 18-foot level in boring A.

According to early geological reports, Juglans and Quercus were dominant trees existing in Howard county. At the 1-foot level these trees have the following percentages: Juglans 12 and Quercus 48 percent. It is very striking that these percentages of the two genera are in close agreement with their importance in earlier economic history of the area.

A high percentage of Betula pollen was found in the upper four levels. Betula in other bogs studied in the state has dropped out of the picture earlier. *Betula pumila* is found as a relic in Kokomo bog today in spite of cultural influences, and here reaches its southernmost limits in Indiana.

There was an absence of the lake forest type dominance during the latter stages of the bog. Acer and Fagus never played an important part in the pollen spectrum. These two genera apparently never had an important position in the forests of Howard county, if their low pollen representations present a true picture of the actual status of conditions. Acer and Fagus at no time threatened to surpass any of the other broad-leaved associations. Fagus and Acer, according to Potzger (11), occur on the north-facing slopes, while Quercus and Carya are present on the south-facing slopes, soil moisture playing an important role in their distribution. The land surrounding Kokomo bog is not strikingly elevated, and, for some edaphic reasons not yet accounted for, Fagus and Acer were never present to any great extent.

The postglacial succession of vegetation as revealed by the pollen determination in Kokomo bog shows the following stages: Abies-Picea, Abies-Picea-Larix, Quercus-Betula, Quercus-Carya, Quercus-Betula, Quercus-Juglans-Carya.

There is a marked similarity between the results obtained from Lake Cicott (17) and the pollen percentages of Kokomo bog. This condition could be expected, since these two bogs are separated by only 21 miles north-south distance and 17 miles east-west distance, Kokomo bog being southeast of Lake Cicott bog. Abies and Picea showed a longer period of dominance and a longer period of presence in Kokomo bog than in Lake Cicott bog. Pinus was present throughout the spectra in both bogs. It reached a position of dominance from the 26- to the 21-foot level in Lake Cicott bog, but never gained such a position in Kokomo bog. However, the peak of abundance (10-17 percent) of Pinus in Kokomo bog coincided with the close of its period of dominance in Lake Cicott bog. Quercus appeared considerably earlier in Lake Cicott bog than in Kokomo bog, but its period of dominance practically coincided in the two bogs. Quercus thus had a much longer period of competition in rising to a position of dominance in Lake Cicott bog than in Kokomo bog, where it rose to dominance in two foot-levels after its appearance. It is interesting to point out also that while Quercus rose more rapidly to a position of dominance over Abies and Picea in Kokomo bog, the period of competition during the decline of the latter two was much longer. There is a much closer similarity in the two bogs with respect to the time between appearance and a position of codominance on the part of Carya. These points are summarized in table II.

TABLE II

Comparison of Main Features of Lake Cicott Bog and Kokomo Bog

	Lake Cicott	Kokomo
Abies—Presence	31- to 21-foot level	32-18
Dominance	31- to 29-foot level	32-22
Picea—Presence	21- to 13-foot level	32- 6
Dominance	None	32-22
Pinus—Presence	31- to 1-foot level	32- 1
Dominance	26- to 21-foot level	Never dominant but reaches peak in 21- to 20- foot level
Quercus—Presence	30- to 1-foot level	23- 1
Dominance	20- to 1-foot level	21- 1
Carya—Presence	21- to 1-foot level	18- 1
Codominance	17- to 1-foot level	15- 4
Marl—	31- to 30-foot level	32-21

It should be noted, also, in comparing Kokomo bog with Lake Cicott bog, that the former had a very much longer period of open water than the latter, as evidenced by the presence of but 2 feet of marl in the latter as compared to 12 feet in the former. Whether this has any bearing upon the longer period of persistence of Abies and Picea in Kokomo bog is not clear, but there is a period of 15 to 18 foot-levels separating the top of the marl and the disappearance of Picea in the two bogs.

SUMMARY

1. A typical Canadian type coniferous forest during formation of the lowest levels is evidenced from pollen analysis of Kokomo bog.
2. A deciduous forest replaces the boreal forest, which continues to the surface.
3. Quercus and Carya were the climax genera of the bog after the disappearance of Abies and Picea.
4. A high percentage of Betula was found in the upper six foot-levels.
5. Climatic conditions ranged from a cool humid to warm dry.
6. The alkalinity of the bog increased with depth.
7. The following forest succession is shown: Abies-Picea, Abies-Picea-Larix, Quercus-Betula, Quercus-Carya, Quercus-Betula, Quercus-Juglans-Carya.
8. The rapid disappearance of Abies and Picea may be due to the removal of the cold seepage waters from the retreating glaciers by the Wabash river.
9. *Betula pumila* reaches its southernmost limit of present-day distribution in Indiana at Kokomo bog.

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A POLLEN PROFILE OF OTTERBEIN BOG, WARREN COUNTY, INDIANA

By Ruth Rebekah Richards

This paper is one of a series of similar analyses being made by the Botany Department of Butler University in a study of tree-pollen types from the peat bogs of Indiana. From this detailed study the forest types of Indiana succeeding the periods of glaciation to the present can be partially and fairly accurately reconstructed. The distribution and frequency of the plant life as determined from this study in turn serves as an index to the different climatic changes which followed the recession of the glacial periods.

Indiana is particularly well adapted for this type of study, as the northern half of the State underwent three periods of glaciation, referred to as the Illinoian, the Early and the Late Wisconsin ice sheets, each of which left in its wake small lakes and kettle holes, some of which still remain as bodies of water and some of which have been completely filled or drained. Due to favorable conditions of preservation, a series of records has been left in these bogs in the form of pollen grains and other plant remains. Of the latter type of fossil remains, Potzger (13) reports extensive deposits in the Blue river valley. The pollen analysis in Indiana has to date been largely confined to the central portion of the state, bounded on the south by Indianapolis, Marion county, and to the north by Cass county. It is to be expected, therefore, that these bogs will show certain similarities and parallels.

Gleason (5) points out that in the Middle West certain successional tendencies of the three major types of vegetation occur, "especially the tendency of the deciduous forests to succeed the prairies toward the west and the coniferous forest toward the north." It seems that conifers of the type found in Canada were forced southward as the glaciers advanced, and then in turn followed the receding ice to the north. Indiana has a wide variation in her plant life because of geographic position. Indiana is bordered on the west by semiprairie regions, with each hundred miles west of the Wabash river along the fortieth parallel showing a marked diminution in winter rainfall (Gleason, 5); on the north by the Dune regions, and the coniferous forests of northern Michigan; on the east by types of plant life, some of which have migrated from the Alleghany regions; and to the south by flora of the warmer, more temperate regions of Kentucky and Tennessee. Today, types of plant life of each of these regions are found within the boundaries of Indiana.

These pollen studies are an effort to trace the development of the great vegetational belts in Indiana during postglacial times, which here shows a very definite progress in one direction without fluctuation as is so frequently found in the records of more northern bogs. The records from Otterbein bog are; thus, only another link in the chain of evidence left us in the fossil records by mighty vegetations which have long since moved on.

The customary diagrammatic presentation of a pollen profile is difficult to read where numerous genera have similar percentages. For this reason the style of diagram used by Janson and Halfert (10) was adopted for use in this paper.

GEOGRAPHICAL LOCATION AND CLIMATIC CONDITIONS

The Otterbein bog is located near Otterbein, Indiana, in Warren county, and is on the same latitude as a bog near Hartford City, Blackford county, Indiana, and as the Kokomo bog, Howard county, Indiana (8). A paper on the latter bog, analyzed by John W. Howell, appears in this issue of the Butler University Botanical Studies. Topographically, Warren county "consists of two areas of smooth to undulating prairie and a belt of low, hilly relief. The main smooth area lies along the western side of the county, broadening northward, and the other lies in the northeastern part. The smooth area in the northeastern part of the county is separated into two parts by the upper part of Big Pine creek, the western and smaller part being less well preserved and less typical than the eastern" (6). According to Deam's (3) Botanical Areas of Indiana, the portion of Warren county in which the bog is located is at the very border of the Lake Region and Prairie areas of plant life of today.

Otterbein bog is an area roughly resembling (on a map) (6) a lady's slipper. The length from "heel to toe" is approximately two miles, and lies in a northeast-southwest direction. The "heel" is about one mile wide in a north-south direction. The area lies in the extreme northeastern corner of Warren county about three miles north of Greenhill and about 1.5 miles southwest of Otterbein. It is at present a vast expanse of sedge-grass meadow, the dominant grasses being Calamagrostis and Phragmites.

The bog is probably of the kettle hole type and was once an open lake, as evidenced by the presence of twelve feet of marl below the peat. When Warren county was first settled, "much of the prairie was too wet for cultivation, and a number of marshes which had not reached the state of 'wet prairie' were scattered throughout its area" (6). Drainage at present is through ditches and tile drains leading into Little Pine creek, which in turn drains into the Wabash river. The bog is of unusual interest because of its proximity to the present-day prairie areas of Indiana which lie only a few miles to the north, and because of its proximity to the northern limits of Early Wisconsin drifts. The area is bordered on the northeast by a higher wooded area, where the soil is of the Bloomington Moraine series.

Wide variations in both temperature and rainfall occur in Warren county. Periods of drought are common. "The prairie belt is marked by wider variations in temperature and a smaller annual rainfall than the forested sections" (6).

METHODS

The material used in the pollen analysis was collected in 1936 by members of the Botany Department of Butler University. The borings were made with a peat borer of the cylinder type, with a movable sleeve. Two borings were made, one at the northern and the other at the eastern part of the bog, through soil analyzed by the U. S. Department of Agriculture (6) as "muck". "It is composed largely of organic matter formed by the accumulation and decay of remains of various plants, principally Sphagnum moss, under wet conditions" (6). The first boring, referred to as A, was made through 44 feet of deposition, consisting of 32 feet of peat and 12 feet of marl. The second or check boring, B, was made through only the 32 feet of peat. The samples were placed into small bottles, labeled according to their respective foot-levels, and the bottles sealed by dipping into paraffin to prevent drying. No pollen count was made of the B samples, as experience with a number of check counts in Indiana bogs has indicated slight variation in two borings from the same bog.

The color of the samples from the twelve feet of marl varied from black at the 32 foot-level to brown in the 34 and 35 foot-levels, brownish-gray in the 36 through 39 foot-levels, and definitely bluish-gray from the 40 foot to the bottom 44 foot-level.

Geisler's (4) method was used in preparing the peat samples for analysis. As the detail of this method has been completely described and discussed in previous botanical papers of Butler University, the writer will not review it here. Two percent aqueous gentian violet was used as stain. The stained pollen grains were found to show structure more clearly after the prepared slides had stood for a period of twelve hours or more. Six or eight drops of the stain were found to be necessary in staining the pollen grains from the lower levels. This was also true in some of the foot-levels above the marl, this condition probably being determined by the degree of acidity or alkalinity of the material used. The average number of pollen grains present was found to vary greatly, as in some instances four to six slides were examined for one level, while in other cases less than one-half of a single slide gave a count of two hundred grains. The highest number of pollen grains present was in the 32 and 33 foot-levels.

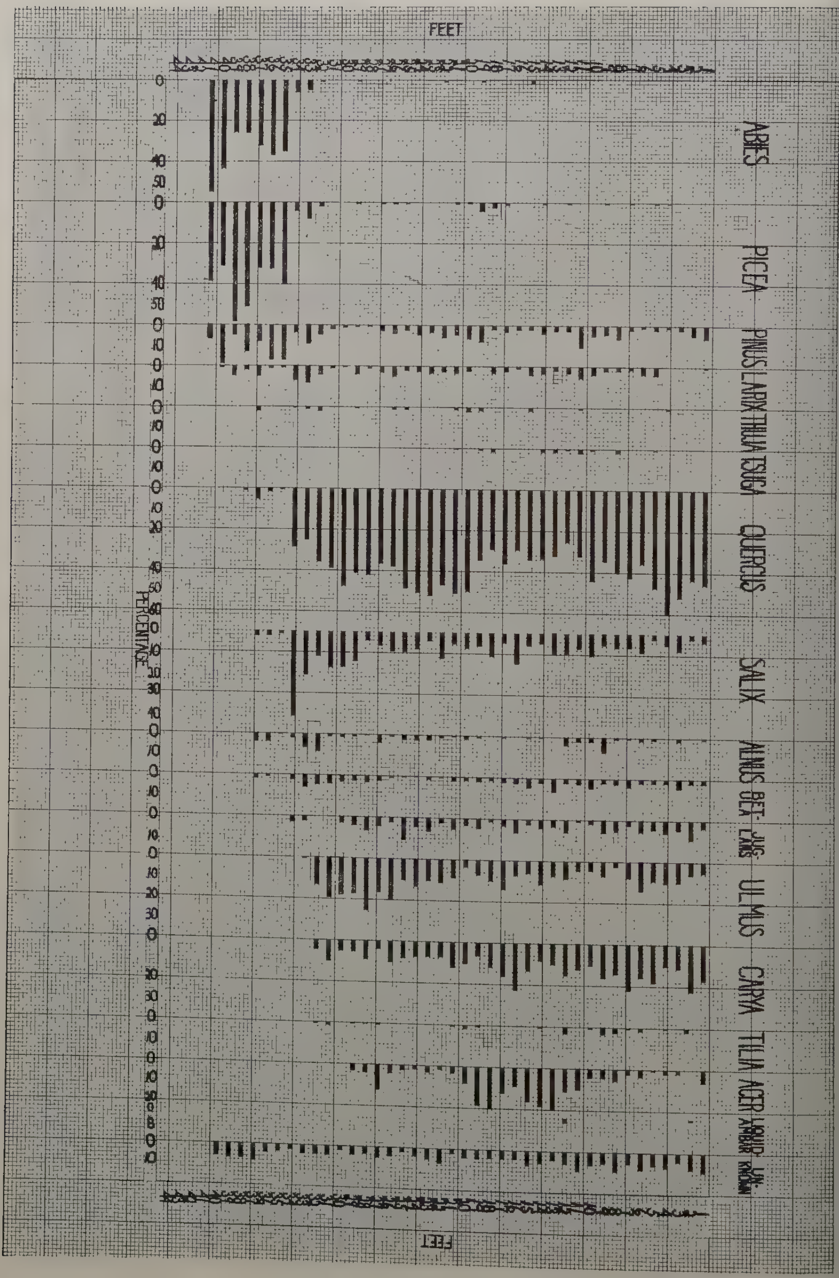
One hundred and fifty pollen grains were counted from the top or surface level through the 27 foot-level. Two hundred pollen grains were counted from the 28 foot-level to the 36 foot-level, inclusive, and only 100 grains at each level from the 37 through the 40 foot-level. This reduced number is no doubt fully adequate for an accurate record, since pollen of only three conifers was present. The remaining levels, 41 through 44, showed a very low number of pollen grains. Because of this the writer did not include the pollen count of the last three feet of the bog in the results given in the pollen profile of figure 1, although ten slides were examined for each of these levels. The limited number of grains present were all Abies, Picea, and Pinus, as in levels immediately above.

Pollen determination and identification were based largely upon the written descriptions and diagrams of Sears (15), Lewis (11), and Wodehouse (17). Frequent comparisons were also made with prepared slides of modern pollen. Figure 1 presents the pollen profile in a summary, indicating the analyses of percentages of pollen grains identified at each foot-level. In instances where fragments of Abies, Pinus, and Picea were present, or where the pollen grain was mounted in a folded position so as to make its identification uncertain, it was tabulated as "unknown."

RESULTS

The lower levels of the bog were characterized by high percentages of Picea, Pinus, and Abies, which were dominant from the 35 to the 44 foot-level. Abies exceeded Picea and Pinus in the lower levels, but at the 39 foot-level Picea increased and either equalled or exceeded Abies

FIGURE 1


FEET
ABIES
PICEA
PINUS
LARIX
THUJA
TSUGA
QUERCUS
SALIX
ALNUS
BET-ULA
JUG-LANS
ULMUS
CARYA
TILIA
ACER
LIQUID-AMBAR
UN-KNOWN
PERCENTAGE
FEET

to the 34 foot-level. Abies was found at intermittent levels until the 15 foot-level, and disappeared entirely after that. Picea and Pinus decreased in importance in the upper two-thirds of the profile, but persisted as relics in the top levels.

Larix first appeared at the 40 foot-level and persisted in small percentages throughout the pollen profile at every level except 2-4 and 19. Very small numbers of Thuja pollen were found at intervals from the 37 through the 4 foot-level. Tsuga was found first at the 21 foot-level, and later in small percentages to the 5 foot-level, where it disappeared. The small numbers of the latter two genera mentioned are probably due to the fact that these pollen grains break down readily and were not preserved in the bogs.

The Abies-Picea-Pinus dominance of the lower levels suddenly decreased at the 34 foot-level and gave way to a Salix-Quercus dominance. Quercus was identified at the 40 foot-level and Salix at the 38 foot-level, but both were present only in small percentages, as the coniferous types were dominant until the 34 foot-level, where they gave way primarily to Salix, which here constituted 42 percent of the pollen. With the exception of this 34 foot-level, Quercus dominated the entire pollen profile from this point to the surface of the bog. Salix appeared at all levels to the top of the bog.

Alnus and Betula appeared simultaneously in the pollen profile at the 37 foot-level. The percentage of each was relatively small. Alnus was found at each foot-level except 2, 4, 13, and 16. Betula was present at all levels from 37 to the top, with the exception of 35. Juglans made its appearance at the 34 foot-level, the same level at which Abies, Picea, and Pinus suddenly decreased in numbers. The former persisted, with the exception of the 32 and 33 foot-levels, to the surface of the bog.

Ulmus was present at every level from the 1 through 33. The elm climax was evidently in the lower levels, as the highest percentage, 25, occurred at the 28 foot-level. Carya was found in small numbers at the 32 foot-level, and gradually increased in numbers at the expense of Ulmus. Three Carya climaxes are evident, one at the 16 foot-level, the second at the 7 foot-level, the third at the surface level.

Tilia pollen was found in small numbers at several levels from the 2 to the 32 foot-level. Acer, appearing at the 29 foot-level, maintained only a small percent of the tabulation to the 19 foot-level. From this point to the 13 foot-level Acer was prominent, but from that point gradually decreased until its count was negligible at the top of the bog. Liquidambar was identified at the 12 and 2 foot-levels.

Grass pollen was abundant in the upper levels and appeared at intervals from the surface to the 32 foot-level, where it disappeared. Fagus was not found at any level.

COMPARISON WITH RESULTS FROM OTHER INDIANA BOGS

Kokomo—The Otterbein bog is located at almost the same latitude as the Kokomo (8), Howard county bog, both near latitude 40° 30′. Results of analyses of the Kokomo and Otterbein bogs are similar. Abies and Picea were dominant for about the same number of feet, and in both bogs these genera disappeared rather suddenly. Pinus persisted from the lowest to the top foot-level, although the percentage of pollen present was somewhat less in the Kokomo than Otterbein bog. Larix was more abundant in the Kokomo bog; small percentages of Tsuga and Thuja were found in both. Betula had two climaxes in the Kokomo analysis, one in the lower levels, where 16.5 percent pollen was found at the 18 foot-level, and the second at the 4 foot-level (17.5 percent). In the Otterbein bog Betula was present in small percentages from the 34 foot-level to the surface. Acer was found in higher percentages in the Otterbein locality, but in both cases there was a similar decrease of this pollen near the top levels. Salix was found in much higher percentages in the lower levels at Otterbein, forming a climax (41 percent) at the 34 foot-level, and then gradually decreasing toward the top level, while in the Kokomo bog 7 percent was the maximum of Salix pollen present. Both bogs were similar in that the top level showed a Quercus-Carya climax.

Lake Cicott—The bog nearest the Otterbein bog in longitude is the Lake Cicott bog (16), Cass county, lying a little to the west of longitude 86° 30′, while Otterbein bog is a little to the west of the 87° meridian. Although one bog was deeper than the other, in general there is quite a similarity between the two. Abies, Picea, and Pinus were all prominent in the lower levels, although Picea never became a dominant species in the Lake Cicott bog as it did at Otterbein. Pinus became a dominant species in the Lake Cicott bog, but 20 percent was the highest count found at Otterbein. In both bogs all three genera decreased suddenly, and Pinus persisted in small percentages to the top foot-level. Quercus appeared early in the lower levels of both spectra, and increased to become dominant at the top levels. Tsuga, Thuja, and Larix were identified in both analyses, but were relatively unimportant. Acer was present in higher percentages in the Otterbein bog than at Lake Cicott, and had

6 percent at the top level, whereas Lake Cicott had only 2 percent. Fagus was not found at all in the Otterbein profile. Salix was more prominent in the Otterbein bog, forming a climax at the 34 foot-level. In both instances, the bogs had a Quercus-Carya climax at the top level.

FOX PRAIRIE BOG—The Fox Prairie bog (14), Hamilton county, is different in several respects from the Otterbein bog. Abies and Picea were dominant genera in lower levels of both, but there were two Pinus-Larix maxima in the Fox Prairie bog not found at Otterbein. Although pollen of the top 12 feet of the Fox Prairie bog was not well enough preserved for analysis, the general tendency and indications in the lower levels seemed to be toward a decrease in Quercus, and the appearance of Acer leading to a Fagus-Acer climax, thus being unlike the Quercus-Carya climax of the Otterbein bog.

CRANBERRY POND BOG—The Otterbein bog analysis in general is unlike the Cranberry Pond bog (1) near Emporia, in Madison county. Although both bogs show a dominance of Abies and Picea in the lower levels, there are little other exact similarities. There were Larix-Pinus climaxes in the Cranberry Pond bog, and a high percent of Larix which was not found in the Otterbein bog. Juglans and Ulmus are prominent in a secondary way in both bogs. However, although Quercus was present in high percentages with Carya near the top levels, Carya finally gave way to Acer, so that a Quercus-Acer climax was formed in the Madison county bog. Acer reached only 6 percent in the top foot-level of the Warren county bog, and the climax was Quercus-Carya.

BACON'S SWAMP, MARION COUNTY—Bacon's Swamp, Marion county (12), is located the farthest south of any of the bogs analyzed to date. As in the other bogs, Abies and Picea dominated the lower levels and decreased suddenly. Pinus in this bog, with the exception of two levels, was present in only small percentages, but persisted to the top of the bog. The percentage of Pinus in the Otterbein bog was much higher than that in Bacon's Swamp. Larix was abundant in the Bacon Swamp analysis, but never reached more than 8 percent in the Otterbein profile. Thuja was present in small percentages in both bogs. The Alnus-Betula group, which persisted to the top levels in small percentages at Otterbein, disappeared above the 7 foot-level in Bacon's Swamp. Salix was present in higher percentages in the lower levels at Otterbein. Although the pollen percentage of Ulmus at two of the lower levels of Otterbein exceeded 20 percent, somewhat higher than the percentage found in the Marion county bog, both bogs had a period represented by several feet in the lower levels when elm was prominent. The top-level climax of

Bacon's Swamp was 31 percent Quercus, 22 percent Acer, and 12 percent Fagus. This differs from the Otterbein bog, where Acer had decreased to 6 percent, the climax was Quercus-Carya, and Fagus had not been identified in the pollen profile at any level.

SUMMARY

Generally speaking, the Otterbein bog more nearly resembles the Kokomo and Lake Cicott bogs, because of the Quercus-Carya climaxes at top foot-level. The bogs located farther to the south and east differ in that their climaxes at the first foot-level were Quercus-Acer.

DISCUSSION

Gleason (5) says, "the history of the vegetation of the Middle West, as of every other portion of our continent, is a history of repeated migrations of diverse floristic elements, arriving in the region from various directions, persisting there for various lengths of time, and finally retreating under the pressure of environmental changes which made their position no longer tenable." Such changes are evident in the vegetational succession in the Otterbein bog region.

In a discussion of this kind the fact must constantly be kept in mind that each foot-level of a bog probably represents centuries. The forest types succeeding the last period of glaciation form the post-Pleistocene flora. According to C. E. P. Brook's climatic table, appearing in the text by Huntington and Visher (9), the last great glaciation took place about 18,000 to 30,000 B. C., and was followed at intervals by six phases, each with a different type of climate, namely the severe continental climate, 18,000-6000 B. C.; the continental climate, 6000-4000 B. C.; a warm and moist period, 4000-3000 B. C.; a warm and dry climate, 3000-1800 B. C.; a cooler and moister period, 1800 B. C. to 300 A. D.; and finally a period in which the climate is becoming drier, 300 A. D. to the present. The Otterbein bog shows some correlation with this climatic table, as indicated by a tendency in general in the upper levels of the bog toward a climate which apparently was becoming drier. However, the lower levels of the bog varied from the climatic table, indicating a difference in the time element between the phases and the number of levels involved in the formation of the bog.

Abies, Picea, and Pinus were dominant in the lower 10 foot-levels of the bog. The total amount of pollen of Picea present at some levels exceeded the percentage of Abies. Pinus, although present from the bottom of the bog and persisting to the top levels, never equalled Abies and Picea, so that Pinus never exceeded 20 percent of the total pollen count at any one level. All three species were prominent at the 35 foot-level, and then suddenly decreased at the 34 foot-level, giving way to Salix and Quercus. This more or less sudden disappearance of the dominant coniferous types is indicative of a change in the climatic factors. As the glaciers retreated, it is possible that the cold waters feeding the soil, especially depressions, began to find regular channels of drainage. Cleland (2) uses a series of diagrams after Taylor and Leverett which would indicate the north and western portion of Indiana were drained largely by the Illinois and Kankakee rivers. As the ice had retreated to beyond these drainage channels, the cold waters were removed from the soil by this surface drainage, which resulted in a higher temperature in the soil south of this drainage channel. Reproduction of the conifers was thus interfered with and a vegetational change occurred. With warmer soil conditions, the broad-leaved types began to crowd in. It is a generally accepted opinion of several writers that a warmer period followed that of glaciation, with the winters still cold but the summers increasingly warm.

Although Larix was present at practically every foot-level above 40, the percentage present was relatively small. Thuja and Tsuga, according to Sears (15), break down quickly when wet, and so their representation in any pollen summary is probably not very accurate.

The broad-leaved genera, Quercus, Salix, and the Alnus-Betula group, appeared in very small percentages from the 35 to 40 foot-level, indicating that the climate was growing a little warmer. Picea and Pinus at the 34 foot-level gave way to a Salix-Quercus climax, indicating a change to conditions no longer favorable to the coniferous forest types. The presence of the Betula and Alnus group at these levels would point toward a climate gradually becoming warmer.

From the 34 foot-level to the surface, Quercus remained the dominant genus, with Carya appearing in the upper levels to form a subclimax with Quercus. A Quercus-Carya climax is usually indicative of a drier climate. However, the possibility of different species within the oak genus must be taken into consideration. Quite some variation was found in the size of the Quercus pollen, and in all probability several species, therefore, were represented, but species were not identified. If *Quercus palustris* and *Q. bicolor* furnished the greatest numbers of pollen present, the climatic conditions would be comparable to those favoring Ulmus, Juglans, and Salix, indicating a warmer climate, with more moisture or shallowing water. If the species were *Q. velutina, Q. alba, Q. borealis* or others, the results would indicate a drier climate. Since Juglans, Ulmus, and Carya had appeared in succession in the order named at the 34, 33, and 32 foot-levels, and since Salix was more or less prominent from the 34 to 29 foot-levels, with Juglans reaching its climax at the 25 foot-level, and Ulmus having its peak points from the 26 to 32 foot-levels, the conclusion may be drawn that the climatic conditions of the period covered at these levels were chiefly moist and somewhat warmer.

Acer appeared in small numbers at the 29 foot-level, but was most important from the 11 to 19 foot-levels. Species of Acer were not identified. If *A. saccharinum* or *A. rubrum* furnished the pollen, they would indicate lowland types of forests, such as found associated with Ulmus and Salix. This in all probability is true, as the pollen profile indicated an increase of Salix at the 16 and 18 foot-levels, and of Ulmus at the 14 and 18 foot-levels. This again would indicate warmer, moist atmospheric conditions. In a discussion of Acer it is also well to bear in mind the possible differences that may occur between the wind and insect pollinated species.

Liquidambar was found at two levels. This is the first pollen of this genus to be identified in the series of pollen studies in the laboratory of Butler University. However, Liquidambar was found by Houdek (7) in two bogs of northern Indiana. There may be some doubt regarding the identification of this pollen, since the genus is typically a southern one. It is possible that the grains were from a species of Amaranthus, although the size closely resembled Liquidambar and was only a few microns smaller than the measurements given by Sears (15). Samples of modern pollen were not available for comparison.

The fact that grass pollen was so prominent in the top levels might be of significance as to the time when the prairie extended into Indiana, indicating also a drier period. On the other hand it may possibly indicate only a shallowing lake with succession to sedge-meadow with Calamagrostis and Phragmites as dominants.

SUMMARY

1. Dominance of the Abies-Picea-Pinus pollen from the 35 to the 44 foot-level indicates that at the time the bog was formed a forest type similar to the present Canadian forests existed. Picea and Pinus persist in small percentages to the surface, with Abies disappearing entirely above the 15 foot-level.

2. Very abrupt transition occurs at the 34 foot-level, characterized by a decided decrease in the Abies-Picea-Pinus dominance, with Salix reaching its maximum which dominated all other genera at this level, and a marked increase in Quercus.

3. Quercus dominates all the remaining levels from the 32-foot to the surface, reaching its climax in the 4 foot-level.

4. Ulmus and Carya appeared in the 32 and 33 foot-levels. All the other broad-leaved genera were present at the 32 foot-level in small percentages, with the exceptions of Acer and Liquidambar.

5. Acer appeared at the 29 foot-level, reaching climaxes at the 18 and 13 foot-levels, and from the latter level decreasing rapidly to the top.

6. Liquidambar was found at the 12 and 2 foot-levels.

7. The top levels indicate a Quercus-Carya climax with an Ulmus subclimax.

8. Briefly, the order of dominance from the 44 foot-level to the surface is as follows:

GENERA	FOOT LEVELS	PROBABLE CLIMATE
Abies-Picea-Pinus	44-35	Cool, moist
Salix-Quercus	34	Cool, moist to warmer
Quercus-Salix	33	Cool, moist to warmer
Quercus-Salix-Ulmus	32-29	Cool, moist to warmer
Quercus-Ulmus	28	Warmer, moist
Quercus-Ulmus-Acer	27	Warmer, moist
Quercus-Ulmus-Carya	26-21	Warmer, moist
Quercus-Carya-Acer	20	Warmer, dry
Quercus-Acer-Carya	19-13	Warmer, dry
Quercus-Carya-Ulmus	12-1	Becoming drier

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